



Synthesis of Literature on the Use of Water-Stained Leaves in the Delineation of Wetlands

PURPOSE: This technical note synthesizes the literature reviewed in a bibliography, WRP Technical Note HY-DE-6.1. In particular, it examines factors that could potentially influence the occurrence of water-stained leaves in wetland conditions. It also provides suggestions regarding the use of water-stained leaves as a field indicator in the wetlands delineation process.

BACKGROUND: The 1987 *Corps of Engineers Wetlands Delineation Manual* and the 1989 *Federal Manual for Identifying and Delineating Jurisdictional Wetlands* described three criteria for delineating wetlands: hydrophytic vegetation, hydric soils, and wetland hydrology. Evidence of all three parameters should be present before an area is considered to be a wetland subject to Federal jurisdiction.

According to the Manuals, in order to meet the wetland hydrology criterion, an area must be saturated to the surface or inundated for at least 5% of the growing season (1987) or one week or more during the growing season (1989) in most years. It is difficult to meet this criterion directly because quantitative data on surface water or groundwater levels are rarely available for specific sites.

In lieu of direct measurements of hydrology, the 1989 Manual suggested eleven field indicators that may be readily observed during a field inspection and can be used as evidence that the wetland hydrology criterion has been met. One of the field indicators that was emphasized in the 1989 Manual was the presence of water-stained leaves on the floor of a forested wetland. These leaves are generally grayish or blackish in appearance. It is believed that the darkening of the leaves is related to submersion.

In August 1991, proposed revisions to the 1989 Manual were published in the *Federal Register*, with a request for comments on the technical validity of the delineation protocol. The presence of water-stained leaves was again emphasized as a indicator of wetland hydrology in the proposed 1991 Manual. Subsequently, Corps Districts were directed to return to the use of the 1987 Manual as a basis for delineations until a new, revised Manual could be developed. Updated guidance regarding the use of the 1987 Manual advised Corps personnel to consider water-stained leaves as a secondary hydrologic indicator.



Figure 1. Water-stained and unstained oak leaves pinned to a tree trunk

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Although water-stained leaves continue to be used as hydrologic indicators for wetland delineation, little is known about the technical validity of this indicator. Accordingly, a literature review was conducted, which has resulted in a bibliography and synthesis of relevant literature.

APPROACH: The literature review consisted of searching pertinent electronic databases; reviewing pertinent articles and their cited references; reviewing recently published journals on related subjects; and reviewing references obtained from subject matter experts.

The authors found no articles specifically addressing water-stained leaves.

Articles related to wetlands are numerous, however, and investigations of decomposition continue to be relatively common. Articles that were selected for inclusion in a bibliography, published as WRP Technical Note HY-DE-6.1, deal with aspects of decomposition in wetlands, general aquatic decomposition, or potentially relevant aspects of wetland ecology.

ANALYSIS: While it seems plausible, even likely, that wetland conditions will often produce water-stained leaves, there is virtually no published evidence that relates the occurrence of water-stained leaves to any other criterion or field indicator of jurisdictional wetlands. However, a review of the related decomposition literature revealed several factors that may influence the occurrence of water-stained leaves. These factors are discussed below.

- **Temperature.** The observation that chemical and biological processes are almost universally accelerated with increasing temperature certainly applies to decomposition. If the process that brings about water-stained leaves is a component of decomposition, water-stained leaves might be expected to be formed faster, all else being equal, in warmer seasons and in wetlands at less extreme latitudes. On the other hand, if staining is a time-consuming process that is accelerated at greater temperatures, so is decomposition. Therefore, water-stained leaves might be fragmented and mineralized faster in warmer wetlands and, actually, less abundant and persistent. Thus, temperature may determine the season during which water-stained leaves are found, or the parts of the country in which they are most prevalent.
- **Redox.** Adequate exposure to an aerobic environment may preclude formation of water-stained leaves, but wetlands are well known for their reducing conditions, which greatly influence chemical and biological aspects of decomposition. It has been our personal observation that deciduous leaves kept loosely in aerated water show little color change over time, while similar leaves packed tightly together undergo a rapid (i.e., over a few days) change to a more blue-gray color. The effect of packing is often distinct enough that the centers of adjacent leaves will be discolored while exposed edges will have normal color. If reducing conditions are conducive to formation of water-stained leaves, then water-stained leaves should be observed in wetlands--and many other habitats--where large concentrations of organic matter (and/or inorganic reductants) deplete oxidants in a microenvironment with limited exposure to atmospheric or dissolved oxygen.
- **Water.** Obviously, moisture is the critical constituent of any wetland. The occurrence of water-stained leaves is probably affected by how much water is present, its periodicity (i.e., wet-dry cycling), the duration of wet periods, the seasonality of wet periods (with respect to temperature, leaf condition, animal activity, etc.), and whether there is sufficient current to transport oxygen and other chemicals or even to move and perhaps abrade the leaves.

Moist conditions are nearly always more conducive to leaf transformations than dryness. Some studies have found that plant tissue decays faster in alternating wet-dry conditions than in either

continuously dry or saturated environments. Moisture provides a solvent for minerals and a medium for surface reactions such as adsorption. Moisture promotes microbial proliferation and enzymatic activity. At the same time, water drastically slows the diffusion rate of oxygen to sites of biological or chemical demand, thus leading to establishment of reducing conditions.

Sites with different amounts of water, different hydroperiods, or different flows will show highly varying rates of leaf transformation. Leaves that fall to a dry forest floor may simply be washed away or buried during the next inundation, while the same leaves falling into wetter conditions may be exposed to very different treatment, leading to discoloration.

- pH. Virtually all studies of effects of pH show that increasing acidity dramatically retards microbial decomposition of plant tissue below a threshold of about pH 5. Wetlands subject to anthropogenic acidification may show unusual effects, but most wetlands probably have pH values conducive to microbial decay. However, the effect of pH on physicochemical transformations such as adsorption of coloring materials to leaf surfaces is apparently unstudied in wetlands.
- Nutrients. Nutrients in sediments and overlying water have been shown by many investigators to influence transformation of detrital leaves. While the nutrient content of wetland soils and overlying waters has been reported often, no relationship has been established between wetland soil or water nutrient content and the coloration of the leaf litter. A likely hypothesis is that leaf discoloration results from precipitation of metal sulfides on leaf surfaces as a result of the same conditions that cause color changes in wet, anoxic soils. It is uncertain what elements are involved and in what concentrations they would need to be present to produce water-stained leaves.
- Sediments. At least part of the color of water-stained leaves may result from a coating of fine soil particles that settles onto the leaves. Particles that are associated with leaf surfaces may compete for adsorption of minerals or, conversely, serve as nuclei to raise concentrations of potentially coloring reactants. Soil particles could also protect the leaves from microbial processes, perhaps by causing complexation of exoenzymes. Severe flooding may bring enough sediments to bury fallen leaves, which quickly promotes anoxia around the leaves. Burial may result in leaves with a different color than those of unburied water-stained leaves. Additionally, rapid sedimentation may result in leaves buried to the extent that water-staining is not apparent.
- Light. Light has been shown to inhibit microbial degradation of plants in water by stimulating growth of photosynthetic microflora. Light may also affect the appearance of detrital leaves either by enhancing color photochemically or, more likely, by destroying color formed in nonphotoreactions.
- Microorganisms and animals. In most benthic communities, the predominant reason for disappearance of detrital leaves is activity of microbes. Fungi, especially aquatic hyphomycetes, are particularly effective in aerobic habitats. Where there are large populations of detritivorous immature insects, animals accelerate mineralization by fragmenting leaves and, in some insects, exposing them to effective gut microflora. Microbial activity may induce discoloration, or perhaps the microbial slime that typically forms during initial decay inhibits discoloration. Water-staining of leaves may also affect microbial and benthic communities by influencing normal succession of decomposing microorganisms, or by making the leaf a less preferred food source.

- Plant species. Leaves of different species respond very differently to decay processes. Leaves have been classified by species with regard to their rates of disappearance in a variety of experiments. Factors that influence decay rates are leaf size and shape, content of nutrients (especially nitrogen), structural compounds such as cellulose and lignin, and presence of metabolic inhibitors, largely polyphenolic "tannins." Clearly these characteristics will likely influence leaf discoloration as well. For example, high concentrations of protein in some leaves may offer more sulfur to react with metals to form a dark surficial precipitate. If leaves are not equally susceptible to discoloration, application of this field indicator is probably dependent upon the species composition of the area in question.
- Leaf condition. Even leaves of the same species undergo varying rates of decomposition depending upon their initial condition with respect to senescence, dryness, and exposure to heat and rain. Presenescent leaves removed by unusual winds are far more nutrient-rich and leach materials faster than do leaves that have been shed by natural abscission. Leaves that remain on the tree after senescence and are exposed for relatively long times, e.g., beech (*Fagus* spp.) and many oaks (*Quercus* spp.), are often sun-bleached and preleached. Heating and drying can cause irreversible complexation reactions between nitrogenous and structural components of leaves but usually accelerate losses by leaching. Drying of fresh tissue makes it leach dissolved materials faster but retards its overall rate of mineralization. It is reasonable to expect that such initial conditions might influence the sensitivity of leaves to staining if leaf color is more than a mere abiotic coating.

CONCLUSION: From an examination of the decomposition literature and wetland ecology literature, it is evident that many variables in wetlands can influence the formation of water-stained leaves. These variables should be considered, in a general sense, when decisions about water-stained leaves are made in the field.

Although there is little technical evidence that directly relates the presence of water-stained leaves with jurisdictional wetland criteria, the frequent occurrence of these darkened leaves in wetlands and the obvious association of water-stained leaves with inundation makes them an indicator worthy of further consideration.

Until more research on the subject yields other pertinent results, it is suggested that water-stained leaves continue to be considered in the delineation process as a secondary hydrological indicator. However, field personnel should be aware that, like drift lines and water marks on trees, the presence of water-stained leaves does not necessarily indicate that inundation of the area occurred for a sufficiently long period of time or during the right time of the year to positively conclude that the hydrologic criterion for jurisdictional wetlands has been met.

REFERENCE:

USAEWES. Jan 93. "Literature Review on the Use of Water-Stained Leaves in the Delineation of Wetlands," Wetlands Research Program Technical Note HY-DE-6.1, Wetlands Research and Technology Center, Vicksburg, MS.

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